APPARATUS FOR DEVELOPING A DYNAMIC SERVO SIGNAL

FROM DATA IN A MAGNETIC DISC DRIVE AND METHOD

BACKGROUND OF THE INVENTION

1.   Field of the Invention.

The invention relates generally to using information about errors for improving extracted data sensed from stored data and more specifically relates to apparatus for using information about the extent of errors wherein a transducer is used to sense stored data having at least one constraint from predetermined storage locations. The transducer generates a signal containing at least one constraint and any errors introduced into the sensed data during the sensing. An input device, which in the preferred embodiment is a detector, is responsive to the signal from the sensor to generate a control signal containing information about the extent of errors and extracts a data signal. An output device is responsive to the control signal to perform a control function to effectively improve the extracted data signal as a function of the extent of errors in the sensed data. In addition, the transducer may have at least two sensors or two transducers may be used to produce a first signal and second signal which is applied to the input device to extract a first data signal and a second data signal wherein the output device is responsive to the control signal and to the first data signal and second data signal to derive a data signal therefrom having the least number of errors.

The apparatus accomplishes this control function by: (i) using the control signal to produce a dynamic servo signal , which in the preferred embodiment is in the form of a

substantially continuous servo signal, to adjust a transducer or transducers position to improve alignment of the first transducer relative to predetermined storage locations, which in the preferred embodiment is a track; (ii) deriving, from data signals extracted from signals sensed from two or more transducers or sensors, a data signal having the least number of errors; or (iii) a combination of producing a dynamic servo signal and deriving a data signal having the least number of errors.

In the preferred embodiment, the input device or detector generates a position error signal from the signal received from the transducer and that position error signal is used as a servo signal for adjusting the transducer position to improve alignment of the transducer relative to the predetermined storage locations.

This invention also relates to a method for using information about errors for performing a control function to improve the extracted data from the stored data in the predetermined storage locations as a function of the extent of errors in the sensed data.

In the preferred embodiment, the invention relates to the field of reading or reproducing from and writing data to mass storage devices, such as magnetic discs.

Also, in the preferred embodiment, the apparatus and method improves the extracted data that is read or reproduced by deriving from among two or more data signals by deriving therefrom the data signal having the least number of errors, or from a combination thereof. This invention is based on the principle that when at least one constraint is added to the data,

this constitutes prior knowledge of the expected data signal in

the absence of noise or other impairments. Such knowledge can be

exploited, such as for example, by making a computation or

comparison between the expected data signal including the at

least one constraint and the observed data signal including the

at least one constraint, to develop a control signal representing

the extent of errors introduced into the signal sensed from the

predetermined storage locations by the transducer, transducers or

sensors. The so developed control signal can be used to develop

a dynamic servo signal in the form of a substantially continuous

position error signal which is used to improve head/track

alignment using conventional apparatus and methods.

In another embodiment of this invention, by reading and

calculating the position error signal on a substantially

continuous basis, an effective servo sampling rate is achieved

that is much higher than the sampling rates of the state-of-the

art apparatus and method.

In the writing mode using a magnetic head, the recorded data

is read and the head position is adjusted using the servo system

up to the instant the head begins to write thereby improving the

quality of the written data on a track.

In yet another embodiment of the present invention, the

magnetic head or transducer may contain more than one read

sensor. By using the teachings of this invention, the signal

representing the extent of errors may be used to derive a data

signal containing the least number of errors from the more than

one data signals.

In a further embodiment of this invention, deriving the data signal which contains the least number of errors and adjusting the head position to improve alignment with the predetermined storage locations in response to a control signal representing the extent of information about errors may be used in combination to improve the extracted data signal.

2.   Description of the Prior Art

It is well known in the art that magnetic discs operate by providing a surface capable of being magnetized in individualized storage locations or in predetermined storage locations. One or more read/write heads are used for interacting with or transducing with the predetermined storage locations for sensing data store at the predetermined storage locations. The magnetized surface is rotated at relatively high speed, thus presenting each predetermined storage location on the surface to the read/write heads or transducers. The use of and operation of transducers for recording and reproducing data from predetermined storage locations from mass storage devices, such as for example a rotating magnetic disc memory system, optical memories, ·magnetic tape and the like is well known in the art.

It is also known in the art to record or store at predetermined storage locations data or information on rotating surfaces, such as for example, magnetic discs and optical discs. The term "predetermined storage locations" as used herein means the individualized area on a surface, such as for example a predetermined or addressable location on a treated surface area in a rotating memory storage device, which contains or stores data or information. In a rotating memory storage device, which

utilizes magnetic media as a magnetic recording surface, the data
or information is stored as a series of magnetic field
transitions on the magnetic recording surface. Such series of
magnetic transitions are included in the term "predetermined
storage locations". The predetermined storage locations are
generally recorded or stored in tracks on magnetic media.

Data is read from the predetermined storage locations on the
magnetic media using a transducer that interacts with the
recording media as a write transducer interacted with the
magnetic media when the data or information was recorded or
stored. In reading or sensing previously written data from a
discrete storage location, the transducer, which functions as a
read sensor, must be positioned over or aligned with the tracks
on the recording surface where the writing transducer has written
or stored the data. Typically, the width allocated to a track of
recorded or stored data is wider than the width of the actually
recorded predetermined storage locations. Further, the width of
the sensor used for reading or sensing the stored data has a
width that is less than the width of both the track and of the
discrete storage location.

In magnetic discs, data is generally disposed on generally
circular tracks, each on the surface of the disc and oriented
with its center coaxial with the physical disc. The read/write
heads, sometimes referred to as read/write transducers, are
disposed in a head/arm assembly so as to be adapted to be moved
to a selected track, under control of a disc servo controller.

The state-of-the-art rotating memory systems store as much
data as possible on the magnetic disc. This, in turn, requires

that the individuated locations or predetermined storage
locations of data or information be as small as possible.
Further this requires that the tracks on the magnetic media be as
close together as possible.

The sensor or transducer for sensing or reading the stored
data from predetermined storage locations on magnetic media must
be positioned in alignment with the track during the sensing or
reading process. The sensors or transducers are operatively
connected to arm assemblies, which are sometimes called head/arm
assemblies in rotating magnetic disc storage systems, which are
adjustable to cause the sensor or transducer to be positioned
within the width of the predetermined storage locations
containing the stored or written data. If the transducer is
positioned within the width of the discrete storage location, the
transducer is in precise alignment with the predetermined storage
locations and senses or reads the stored data to produce a signal
from the sensor with the optimum signal-to-noise ratio and with
low data errors.

It is known in the art that, as the track density increases,
it becomes more difficult to precisely align the read/write heads
or sensors with the tracks. Such misalignments or variances in
alignment may occur during reading and writing of data due to
variances in operating conditions. The read/write heads or
sensors may vary from precise alignment with the tracks by any
one of: (i) horizontal displacement from the actual track, (ii)
angular orientation or skewing relative to the actual track, or
(iii) vertical displacement from the actual track due to the
read/write heads or sensor lifting off of the disc. As a result

of any of the above variances in operating conditions, the read/write heads or sensors may not precisely be aligned with the track, and such misalignment or variances in alignment change with time.

As a result of such misalignment, the transducing operation of the read/write head or sensors in reading or recovering data from the predetermined storage locations becomes degraded. In addition, the sensed data contains errors or the data sensed by the sensor becomes deformed which results in errors in the electrical signal representing the data or information.

Typically, the transducers were positioned over the rotating magnetic media. Initially, stepper motors were used as actuators to move the sensors to a specific position and the sensors remained in that position during reading and writing of data. This is referred to herein as the "Stepper Motor Method"

One disc drive system which used a process for determining the center of data disc tracks is disclosed in United States Patent 4,816,938. In United States Patent 4,816,938, a transducer head is positioned to one side of a track. The transducer head repeatedly reads the track and is microstepped across the track. The number of microsteps taken at the position on each side of the center of the track, where a certain number of error corrections occur, are designated as the boundaries of that track. The center of the track is then calculated as being half-way between the boundaries. By using the microstep off-sets for the centers of two tracks, a correction factor can be calculated to compensate for thermal expansion of the disc.

Another method known in the art for controlling transducer
head/track alignment is to use a closed loop servo system having
a dedicated servo surface. In this method, continuous sequences
of special positioning signals were recorded on the servo surface
in every track on the servo surface. Deviation signals were
developed using the prerecorded sequences and such deviation
signals were used in a feedback technique to adjust the position
of all of the other read/write transducer heads. This is
referred to herein as the "Servo Surface Method"

Another known method includes "servo bursts" being
prerecorded around each track to improve the alignment of the
data head with the data track. A "servo burst" is a short
special position signal, i.e., equivalent to the length of few
bits, prerecorded in each track, used in a servo system for
maintaining head/track alignment.

The prerecorded "servo burst" pattern is presently used for
generating a signal indicating the magnitude of misalignment
between the data head and track and the direction that the head
was displaced from the track center. Special cases provide for
prerecording a "servo burst" in each sector of a disc. The so
generated signal is used to locate track position more precisely
in terms of predefined actuator positions and functioned to place
the head in alignment with the track.

The recorded servo bursts are used to provide an open loop
servo system to more accurately and rapidly position a head
relative to a track prior to reading of and writing of data onto
and from the track and to adjust or correct head position during

the process of reading and writing of data. This is referred to herein as the "Servo Burst Method".

United States Patent 5,233,487 discloses a rotating media storage system that compensates for thermal and mechanical errors in the position of the data detector, or read head, with respect to the written data. The compensation is accomplished by measuring the error rate of written data as a function of the read offset of the detector in that error rates become increasingly large as the sensed noise to signal ratio becomes large. As the offset of the head becomes misaligned with the track, the sensed noise to signal ratio increases. When the data storage system is initially activated, the detector counts the number of errors detected in reading written data for various read offsets. When the number of errors reaches a target rate, the read offset corresponding to the target rate is saved. The procedure is performed on either side of the data track. During operation of the storage system, thermal and mechanical operational errors occur in the system and similar error rate data and offset data are developed for these operational conditions. The so developed error rate and target error rate are used to cause the detector to be re-centered with respect to the write transducer position between the new offsets on either side of the tracks.

Use of a dual-striped magnetoresistive head with a conventional servo system was disclosed in an article entitled *Estimation of Track Misregistration by Using Dual-Stripe Magnetoresistive Heads*, by Lian Na Zhi Gang Wang, Desmond J.

Mapps, P. Robinson, Warwick W. Clegg, D. T. Wilton and Yoshihisa

Nakamura, which appeared at Pages 2348 to 2355 of the IEEE

TRANSACTIONS ON MAGNETICS, Volume 34, No. 4, July, 1998 (the

"Wang et al Reference"). The Wang et al Reference utilized the

principal that when a dual-stripe, unshielded magnetoresistive

("MR") element is exposed to the same stray field from a media

transition, one MR element has a resistance increase and the

other MR element has a resistance decrease. The difference

between the MR elements' output envelopes was demodulated by a

peak value detection circuit and the sum of the two element

signals was considered as a position error signal. The position

error signal was utilized in conjunction with a conventional

servo system and the estimated off track perturbation was used to

supplement the well used sector servo. This system did not use a

constraint within the data or the extent of errors therein.

United states Patent 4,404,676 discloses a method using a

data-dependent code word consisting of redundancy bits, that

marks a boundary of a multi-bit cell. The data-dependent code

word is coded to bear a "mapping relationship" to a data block

within the cell. Embodiments using the data-dependent code word

provide various types of synchronization. Decoders provide block

and bit synchronization for either serial-by-bit data signal or a

serial-by-byte data signal. United States Patent 4,404,676

further discloses that the preferred embodiment is used in a

record/playback system for storing on a storage medium and

subsequently deriving the stored information from the storage

medium. In the system disclosed in United States Patent

4,404,676, encoding means and decoding means are used, each of

which utilizes a data-dependent boundary-marking code word

bearing a predetermined mapping relationship to a data block of a

cell and otherwise being indistinguishable from arbitrarily

selected groups of data bits. The object of United States Patent

4,404,676 is to solve synchronization problems and not to provide

for adjusting head or transducer position or deriving a data

signal having the least amount of errors from two or more data

signals representing the sensed data.

As is well known in the art, a servo system in rotating

memory systems is used to control the positioning of the sensor

relative to the tracks of predetermined storage locations

containing the stored data. Servo systems, which are well known

in the art, include sector servo systems, dedicated servo systems

or other well known servo systems. The function of the servo

system is to compare certain sensed signals with a predetermined

pattern of signals and to use the results of such a comparison to

change position of the sensor or transducer with respect to the

predetermined storage locations to generate the most accurate

reading of the stored data from the predetermined storage

locations.

The known prior art servo systems and methods for sensing

and providing efficient and rapid adjustments of the sensing head

have many disadvantages.

In the Stepper Motor Method, no feedback signals were used

to adjust head position.

In the system and method disclosed in United States Patent

4,816,938 reading of the data or writing of new data must occur

in an open loop system, e.g. no servo loops are used, during

reading and writing of the data. Error correction codes were
used only to help select transducer head position prior to
reading or writing of the data.

With respect to the Servo Surface Method as discussed
hereinbefore, while this method partially achieves the goal of
attempting to align the read/write head with the data track, it
has at least the following drawbacks. First, this method uses
substantial disc space for the servo sequences, which removes
area from the disc that could otherwise be used for data.
Second, the Servo Surface Method results in misalignment between
the servo head and the data head and is not practical for use in
magnetic disc drives having higher areal densities. While the
Servo Surface Method as augmented by United States Patent
5,233,487 provides a correction for changes in the relation
between the servo surface head and data head due to thermal
expansion and other factors, servoing during data reading and
writing is restricted to the servo surface.

The Servo Burst Method as described above is an intermittent
servo system that runs open loop between servo bursts and closed
loop upon the sensing of the recorded servo burst to produce
servo signals for adjusting the head position relative to the
data track. The Servo Burst Method is generally known in the
industry as open loop technology and is the standard today of the
industry for magnetic storage systems. This method, even as
augmented by United States Patent 5,23,487 and the Wang et al
reference, has at least the following drawbacks.

First, if it is desired to improve the sampling accuracy,
additional disc space for the servo bursts would be required.

Second, the accuracy of this method must be significantly
improved upon for use in the state-of-the art high areal density
storage systems

The method disclosed in United States Patent 5,233,487 is
based on the principal that sensing signals outside of the write
width is deemed an off-track read, and when enough of the read
widths are outside of the write width, an error in reading data
is deemed to have occurred. An ECC detection/correction means
senses the error in blocks of data and a counter maintains a
count of the number of errors. When the errors reach a
predetermined error rate, the data detector position is adjusted
to optimize detector read performance. As such, adjustment of
the read head relative to the data track occurs only after the
number of counted errors exceeds a predetermined number of
errors.

The use of a dual-stripe MR head, as disclosed in the Wang
et al Reference, was based on the principal that the signal
waveform changes only in amplitude as the head moves off track,
and does not rely on the data signal having any constraints.

The system and method disclosed in United States Patent
4,404,676 has several limitations when applied to magnetic data
storage systems. During reproduction of the data in such a
system, it is necessary to produce a plurality of individually
identifiable clock signals and each clock signal has reoccurring
clock pulses with the clock pulses of each such clock signal
differing from those of each other clock pulses as to the time of
occurrence. The clock pulses are required to sample a data
signal and to derive a plurality of sample bits that are

congregated and tested. The system includes means for generating

a candidate-valid signal for each candidate cell that is

determined, by such testing, to be a valid cell. As each

candidate cell undergoes such testing, that testing determines

whether the code-word portion of the candidate cell bears the

predetermined mapping relationship to its block-length portion as

is characteristic of a valid cell. Since this system is based on

a serial-by-bit data signal or a serial-by-byte data signal

method, the system is not designed and is unable to produce a

position error signal, or to derive a signal from among multiple

input signals.

     In the last several years, the state-of-the art performance

benchmark for the magnetic hard disc drive industry has been

areal density progression. Areal density is defined as the

number of bits per square inch that can be stored on a magnetic

disc surface and successfully retrieved. Areal density is

determined mathematically by Bits Per Inch ("BPI") multiplied by

Tracks Per Inch ("TPI") (BPI x TPI). As the areal density

increases, the need for an improved head positioning apparatus,

methods and systems likewise becomes necessary due to the

limitations of the prior art systems, methods and apparatus as

described above.

     Areal density for magnetic hard disc drives has been

increasing at a 60% compounded annual growth rate and that rate

is forecasted to continue for at least the next several years.

For example, the areal density for magnetic hard disc drives was

1 gigabit per square inch ("Gb/sq. in.") in 1995 and increased to

4.1 Gb/sq. in. in 1998.

In addition, it is reasonable to expect that at some areal density point, which is presently estimated at about 40 Gb/sq. in., the issue of thermal decay of the stored data on the magnetic media will need to be addressed. It is reasonable to conclude that other storage media, such as for example, chemical and molecular media, may be developed for storage of data in predetermined storage locations.

Increases in TPI will probably depend on the ability of the read head or read transducer to both track the data and to respond mechanically to non-repeatable spindle motor problems and other track misregistration problems.

In 1998, typical BPI is 256,000 and TPI is 16,000 which represent an areal density of about 4.1 Gb/sq. in. For the year 2000, the areal density is forecast to be 10 Gb/sq. in. which corresponds to a BPI of 334,000 and a TPI of 30,000.

It is reasonable to conclude that a track density may exceed 86,000 TPI and, if so, the read head or read sensor will have to follow a written track width of 10 microinches, all of which will require advanced servo systems and data track following technology utilizing the teachings of the present invention.

SUMMARY OF THE PRESENT INVENTION

The present invention discloses a new, novel and unique apparatus for using information about the extent of errors. The apparatus includes a first transducer positioned for sensing predetermined storage locations and generating a first signal representative of data containing at least one constraint from the predetermined storage locations and any errors introduced into the sensed data during the sensing. The apparatus includes

an input device responsive to the first signal for generating a
control signal containing information about the extent of errors
in the sensed data and for extracting a data signal. An output
device is operatively coupled to the input device for receiving
the control signal and for performing a control function in
response thereto to improve the extracted data signal as a
function of the extent of errors in the sensed data.

The output device may be responsive to the control signal to
produce a dynamic servo signal, which may be in the form of
substantially continuous servo signals which are used to improve
alignment of the first transducer relative to the predetermined
storage locations. In the preferred embodiment the dynamic
servo signal may be used to generate position error signals for
head/track alignment in a magnetic disc drive storage system.

Information about the extent of errors is developed on a
continual basis and is not delayed until a threshold condition of
errors is exceeded.

This may take the form of an adjusting element operatively
coupled to the first transducer for receiving and responding to
information about the extent of errors in the control signal and
for adjusting the transducer in a direction to position the
transducer in improved alignment relative to the predetermined
storage locations.

The apparatus may include a second transducer positioned
relative to the first transducer for sensing the predetermined
storage locations and generating a second signal representative
of data containing at least one constraint from the predetermined
storage locations and any errors introduced into the sensed data

during the sensing. In this apparatus, the input device

generates the control signal from at least one of the first

signal and the second signal and extracts a first data signal and

a second data signal and the output device is responsive to the

control signal and at least one of the first data signal and the

second data signal to derive therefrom a data signal containing

the least amount of errors.

In another embodiment, the apparatus includes a first

transducer having at least two sensors for concurrently sensing

the predetermined storage locations and generating a first signal

and a second signal each representative of the data containing

the at least one constraint from the predetermined storage

locations and any errors introduced into the sensed data during

the sensing. The input device generates the control signal from

at least one of the first signal and the second signal and

extracts a first data signal and a second data signal. The

output device is responsive to the control signal and at least

one of the first data signal and the second data signal to derive

by selection therefrom a data signal containing the least amount

of errors.

In addition, this invention includes a new, novel and unique

method for using information about the extent of errors. The

method comprises the steps of: (a) positioning a first transducer

for sensing predetermined storage locations storing data

containing at least one constraint and generating a first signal

representative of the data containing at least one constraint

from the predetermined storage locations and any errors

introduced into the sensed data during the sensing; (b)

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generating in response to the first signal a control signal

containing information about the extent of errors in the sensed

data and extracting a data signal; and (c) receiving the control

signal and performing in response thereto a control function to

improve the extracted data signal as a function of the extent of

errors.

The method also includes the step of receiving being

responsive to the control signal and the first data signal and

the second data signal for deriving a data signal therefrom

containing the least amount of errors.

The method also includes in the step of responding by

adjusting the position of a transducer with an adjusting element

operatively coupled thereto for receiving and responding to

information about the extent of errors in the control signal

wherein the transducer is adjusted in a direction to position the

transducer in improved alignment with the predetermined storage

locations.

The present invention also includes a storage system

comprising a storage media, which may be a two dimensional

surface or a three dimensional volume such as a holographic

memory. The storage system comprises a storage media having

located thereon predetermined storage locations storing data

containing at least one constraint. A transducer is positioned

relative to the storage media for sensing the data containing the

at least one constraint stored in the predetermined storage

locations and generates a first signal representative of the

sensed data containing the at least one constraint and any errors

introduced into the sensed data during the sensing. An input

device is responsive to the first signal for generating a control
signal containing information about the extent of errors in the
sensed data and for extracting a data signal. An output device
is operatively coupled to the input device for receiving the
control signal and for performing a control function in response
thereto to improve the extracted data signal as a function of the
extent of errors in the sensed data stored as data in the
predetermined storage locations.

The output device may be an adjusting element operatively
coupled to the transducer for receiving and responding to
information about the extent of errors in the control signal and
for adjusting the transducer in a direction to position the
transducer in improved alignment relative to the predetermined
storage locations.

In another embodiment, a detection apparatus comprises a
first transducer that is movably positioned for sensing stored
data containing at least one constraint. The first transducer
generates a first signal representative of sensed data containing
at least one constraint stored as stored data and any errors
introduced into the sensed data during the sensing. A detector
is responsive to the first signal for producing a control signal
containing information about the extent of errors in the sensed
data and extracting a data signal. The output device is
operatively coupled to the detector for receiving the control
signal and for performing a control function in response thereto
to improve the extracted data from the stored data as a function
of the extent of errors in the sensed data.

A method is also taught herein for using information about the extent of errors in combination with servo burst signals generated from prerecorded servo bursts.

Therefore, one advantage of the present invention is that a novel, unique and improved apparatus, method, and system is provided for aligning sensors, e.g. disc read/write heads, in an information storage system e.g. a magnetic hard disc drive system or magnetic floppy disc drive system.

Another advantage of the present invention is that disc read/write heads are dynamically aligned with data tracks in response to a control signal containing information about the extent of errors as detected from data generated by the read/write heads with regard to the data containing at least one constraint itself.

A further advantage of the present invention is that the sensed data itself provides substantially continuous feedback of signals containing information about the extent of errors to an actuator for the read/write heads. The information about the extent of errors also provides sufficient information to align the read/write heads with data tracks even when the signal amplitude is not significantly altered or distorted.

A further advantage of the present invention is that the information about the extent of errors is developed on a current basis and the control signal containing information about the extent of errors are generated at the microsecond level.

A still further advantage of the present invention is that information about the extent of errors may be used to derive, e.g. select, one of a plurality of sequences of data, such

sequences extracted from a corresponding plurality of sensors,

e.g., multiple sensors such as magnetoresistive elements disposed

on a read/write head.

A still further advantage of the present invention is that

the information about the extent of errors can be determined in

response to constraints on the data signals as sensed, which

constraints are implicit in or included in the data signals as

recorded. Such constraints can include error detecting or

correcting codes, Partial Response Maximum Likelihood ("PRML")

encoding, Run Length Limiting ("RLL") codes, or other bit

encoding techniques, data formatting, waveform shaping or other

information regarding the consistency of data signals as recorded

and later sensed.

A still further advantage of the present invention is that

the apparatus for producing the control signal can be used to

generate substantially continuous feedback of signals containing

information about the extent of errors in nearly real time and

applying the same to an actuator for positioning the read/write

heads to maintain head/track alignment in combination with the

Servo Burst Method as described above such that the position

error signals from the apparatus are used during the intervals

between servo bursts and, at the time of sensing of a recorded

servo burst that servo burst signal is used to produce servo

signals for adjusting the head position relative to the data

track.

A still yet further advantage of the present invention is

that the apparatus for producing the control signal containing

information about the extent of errors which can be used to

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generate a dynamic servo signal in the form of a substantially

continuous position error signal at a sampling rates

substantially higher than the rate that servo signals can be

generated by the Servo Burst Method as described above such that

the position error signals may be used for adjusting the head

position relative to the data track at substantially higher rates

than the present state-of-the-art systems and apparatus.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other advantages of this invention will be

apparent from the following description of the preferred

embodiment of the invention when considered with the

illustrations and accompanying drawings which include the

following Figures:

Fig. 1 is a pictorial representation of a treated surface of

a storage media containing predetermined storage locations

containing data and includes a partial block diagram of a

transducer, an input device, a device for generating a control

signal and an adjusting element comprising apparatus for using

information about the extent of errors sensed by a transducer

from predetermined storage locations;

Fig. 2A is a block diagram of a recording medium interacting

with a one or more transducers including a read transducer, an

input device and an output device to generate control signals and

to extract data signals for improving the extracted data

utilizing the teachings of the present invention;

Fig. 2B is a block diagram of a recording medium interacting

with a read transducer, a detector, an adjusting element and a

control device for adjusting position of a transducer with an

actuator in response to a dynamic servo signal used as a

position error signals utilizing the teachings of the present

invention utilizing the teachings of the present invention;

Fig. 2C is a block diagram of a recording medium interacting

with a read transducer having two or more sensors, an input

device, an data signal derivation, e.g. selection, device for

improving extracted data signals, an adjusting element and

actuator for adjusting position of a transducer to improve

alignment with a predetermined storage location or electrically

shifting the operating characteristics of the transducer in

response to a dynamic servo signal utilizing the teachings of

the present invention;

Fig. 3A is a pictorial representation of a surface of a

storage media depicting the width assigned to a track on the

surface, the width of a track containing stored data and the

width of a transducer having a write transducer and two read

magnetoresistive elements for sensing the stored data within the

predetermined storage locations defined by the track with the

transducer positioned in alignment with the track containing the

stored data;

Fig. 3B is a pictorial representation of a surface of a

storage media depicting the width assigned to a track on the

surface, the width of a track containing stored data and the

width of a transducer having a write transducer and two read

magnetoresistive elements for sensing the stored data within the

predetermined storage locations defined by the track with the

transducer misaligned to the left side of a track;

Fig. 3C is a pictorial representation of a surface of a storage media depicting the width assigned to a track on the surface, the width of a track containing stored data and the width of a transducer having a write transducer and two read magnetoresistive elements for sensing the stored data within the predetermined storage locations defined by the track with the transducer misaligned to the right side of a track;

Fig 3D is a pictorial representation of a transducer having a write transducer and two magnetoresisitve elements as the read transducers which have an insulative shield therebetween;

Fig 3E is a pictorial representation of a transducer having a write transducer and two magnetoresisitve elements as the read transducer which have a conductive shield therebetween which is responsive to a bias voltage to shift the magnetic operating characteristics of the magnetoresistive sensors;

Fig. 4 is a schematic diagram of an embodiment of an apparatus having a rotating recording surface having predetermined storage locations containing data and having a slider/loading arm for loading and adjusting a transducer relative to predetermined storage locations and other elements for improving extracted data signals using the teachings of the present invention;

Fig. 5 is a schematic diagram of yet another embodiment of an apparatus having a rotating magnetic media recording surface having predetermined storage locations containing data and having a slider/loading arm for loading and adjusting a magnetoresistive transducer having two magnetoresistive elements relative to predetermined storage locations and other elements including a

plurality of amplifiers for receiving the signals generated by
each magnetoresistive transducer for improving the extracted data
using information about the extent of errors;

Fig. 6 is a block diagram of the various steps of a method
of the present invention for using information about the extent
of errors including the various steps of the method;

Fig. 7 shows response curves relating information about the
bit error rate ("BER") plotted as a function of track width and
extent of errors plotted as a function of track width;

Fig. 8 shows response curves of the data signals sensed by
two magnetoresistive elements positioned within a transducer as
shown in Fig. 3A plotted as a function of track position and the
effects of using an adjusting signal to shift the operating
characteristics of one element of the two magnetoresistive
elements;

Figure 9 shows is a waveform of an expected PRML encoded
signal and waveform of an observed PRML encoded signal which is
used to generate a control signal containing information about
the extent of errors in the sensed data;

Figure 10 shows a process flow diagram of a method for
aligning a transducer to predetermined storage locations using
information about the extent of errors in a control signal and
producing improved data signals from sensed data containing at
least one constraint;

Fig. 11 is a schematic diagram of yet still another
embodiment of an apparatus having a rotating magnetic media
recording surface having predetermined storage locations
containing data and having an actuator for adjusting a

slider/loading arm having an magnetoresistive transducer having

two magnetoresistive elements relative to predetermined storage

locations and a plurality of amplifiers for receiving the signals

generated by each magnetoresistive transducer and generating

three signals used as inputs to individual data extraction and

error detection circuits the controls signals and extracted data

signal of which are used for improving the extracted data using

information about the extent of errors;

Fig. 12 is a plot of voltage from each MR element and the

sum of voltages from both MR elements plotted as a function of

off track locations showing the response curves representative of

the inputs to the individual data extraction and error detection

circuits shown in Fig. 11, and

Fig. 13 is a diagrammatic representation of another

embodiment of the present invention of a multidisc storage system

having a first transducer and a second transducer for generating

first signals from different disc surfaces as inputs to an input

device for generating a plurality of control signals each

containing different information about the extent of errors.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In order to better understand the teachings of the present

invention, to set forth certain definitions that apply to the

disclosure and claims as set forth herein and to provide other

technical information and data, the following is provided as

background for this invention.

Background

The word "derive" as used herein means to perform one or more logical processing operations on one or more original electrical signals resulting in a different but related secondary signal based on or taken from one or more of the original electrical signals subject of a logical processing operation resulting in a derivation of one or more of the original electrical signals. For example, a derivation of an output signal from a first data signal and a second data signal with a control signal can be accomplished several ways. The simplest derivation, known a "selection", is to select, by means of a control signal, between the first data signal and the second data signal the data signal that corresponds to the least number of errors averaged over an appropriate interval as the logical operation. Another example of a derivation is an output signal from a first data signal and a second data signal generated by forming a weighted average of the first data signal and the second data signal, as a logical operation, with the weights determined by means of a control signal so as to produce an output signal of the least number of errors. Other derivations are well known to those skilled in the art of deriving an improved data output signal from several sensed signals of the same stored data.

A "flexure" is a flexible loading device that supports a head/slider assembly and is operatively mounted at the end of a loading arm in a head stack assembly.

A "head" is a fabricated device, which typically is in the form of a microchip, that contains one or more transducers or sensors or transducers having elements that function as read and/or write elements.

A "head/slider" is a fabricated element comprising a head and slider that is mounted onto a flexure for loading onto a rotating surface.

A "head/arm assembly" is an arm containing flexures and a head/slider assembly located at one end thereof. The end of the loading arm supporting the head/slider assembly may be articulated.

A holographic memory is a memory in which information or data is stored in the form of holographic images in photographic emulsion or other recording media.

A "position error signal" is a signal representing that a disc head is off track, and the magnitude and direction thereof; and the processing of this signal results in an adjustment of or repositioning of the head relative to predetermined storage locations by an actuator.

A "PRML" is an acronym for "partial response maximum likelihood" that is a method of generating and decoding the analog signal that records data at predetermined storage locations such as along a data track.

A "sensor" is a device for reading or reproducing information stored on a recording media such as for example, an inductive magnet, magnetoresistive ("MR") element, an optical

detector, e.g. charged coupled device ("CCD"), for responding to information stored on an optical storage medium.

A "slider" is a device that supports the head and forms an air bearing between the head and rotating surface to keep the head flying over the rotating surface, which typically is a magnetic disc, at the correct height and carries the electrical leads from the head to the flexure.

A storage medium is a storage device which may be a two dimensional medium such as a magnetic tape, rotating magnetic memory, an optical disc or a three dimensional medium such as a holographic memory.

A "transducer" is a device for interacting with a treated surface for recording and reproducing information on the treated surface. As used herein, the term "transducer" is intended to cover an inductive head, a write transducer, magnetoresistive elements, read transducers, lasers, optical sensors, microphones, CCD devices and the like. Sometimes the term "sensor" is used interchangeably with the term "transducer", and in the context of this invention, a sensor is a read element or read transducer.

Chart I set forth below is a listing of actual head and disc drive parameters for the years 1997 and 1998 and of the forecasted parameters for the future showing the head technology and disc drives in which the present invention has utility:

$T, 0310$

Year	Areal Density (Gb/sq in)	KTPI	KBPI	Read Track Width (Microinches)	Head Technology
1997	2.64	12.5	201	54	MR
1998	4.10	16.0	256	42	MR, GMR
2000	10.00	30.0	334	22	GMR
2003	40.00	61.0	659	17	GMRT
2005	80.00	86.0	926	8	GMRT

CHART 1

Note: MR is a magnetoresistive head.

GMR is giant magnetoresistive head wherein the sensor is formed of a material that utilizes spin-dependent scattering of electrons for sensing data stored at the predetermined storage locations, an example of which is set forth in the IBM RESEARCH BULLETIN dated August 21, 1998 and as shown at the IBM Website www.research.ibm.com.

GMRT is an advanced giant magnetoresistive head wherein the sensor is responsive to read track widths of less than 20 microinches.

Chart II set forth below is a listing of areal density, the KBPI x TPI for such areal density and the magnetic bit sizes for the applicable areal density in which the present invention has utility:

T, 0320

Bits per inch x Tracks per inch	Magnetic Bit Size- (Length) (Micrometers)	Magnetic Bit Size- (Width) (Micrometers)
48kbpi x 2100tpi	10.000	0.710
150kbpi x 6600tpi	3.100	0.150
400kbpi x 25ktpi	0.800	0.064
800kbpi x 50ktpi	0.400	0.032
1,000kbpi x 100ktpi	0.300	0.015

CHART II

Information about data errors is itself a valuable signal and can be determined in response to signals produced by the head, transducer or sensor. The information about data errors can be used to dynamically and rapidly adjust the state of the sensor (such as its position relative to a data track), so as to improve operation of the information storage system.

The apparatus of the present invention provides for using a transducer for sensing from predetermined storage locations stored data containing at least one constraint. The at least one constraint in the data may be in many forms. For the purpose of this invention, a constraint is some aspect of data, or an encoding of the data, or signal generated from the data, such that what is received from the transducer can be compared in some way with what was expected to be received so as to ascertain the extent of the difference. Often, the differences are due to some external effect on the signal carrying the data. The constraint may be an analog constraint, such as a limitation on the frequencies that can appear in the signal or the properties of the signal waveform. The constraints may be digital such as

from an encoding process such as a parity check code or an error-correcting code ("ECC").

Generally, encodings that introduce or impose constraints on signals have the property that the bit string resulting from the encoding is a subset of all possible bit strings of the same length. An appearance of a disallowed bit string, i.e. one that would not be produced by the encoding, in the process of receiving the signal containing the data, shows that the recovered data violates the constraint.

Accordingly, by determining the manner in which the constraint is violated, for example with an ECC, then any errors and extent of errors introduced into the signal can be ascertained, and this information used in accordance with the teachings of this invention.

An example is a Reed-Solomon type ECC encoding of a bit sequence. The ECC encoding will include both the data and the "syndrome" computed from the data (the bit sequence). This has the property that only a subset of the bit sequences, whose length is the length of the data plus the syndrome, is possible. If a signal containing the ECC encoded data is received, the decoding will reveal whether a correct sequence of data bits and syndrome bits is received or not. If not, than the extent of the errors in the signal can be determined, up to some number of errors that depends on the details of the ECC method.

Thus, by using the knowledge about the at least one constraint imposed on the first signal, a control signal containing information about the extent of errors can be

-33-

immediately generated and used to perform a control function in accordance with the teachings of this invention.

Sensors that respond to digital data that is recorded for storage in an information storage system can generate signals that are responsive both to actual data and to errors in reading that data. The system can dynamically determine in response to signals produced by the head, transducer or sensor, both the actual data and information about those errors.

Analog techniques used for encoding individual bits and sequences of bits can be used to determine both the probable actual data and one or more measures of deviation from error-free retrieval of that actual data, e.g. PRML encoding techniques for storing and retrieving data.

PRML encoding techniques are used to encode data as it is stored on a disc drive as is well known in the art. During reading of a segment of data stored in PRML form using the state-of-the-art apparatus and method, the signal being read by the head, transducer or sensor, e.g., an MR head, is sampled at periodic intervals. The sample points are picked to be synchronous with the signal and sampling occurs at points where the signal is expected to take on specific values.

The present invention resides in apparatus and methods for using information about the extent of errors in sensed data for performing as a control function of at least one of adjusting the position of a transducer, such as a magnetic head, to improve alignment relative to a track and deriving from two or more data signals a data signal having the least amount of errors. The apparatus and method use the information about the extent of

errors to perform a control function for reproducing the data

stored in predetermined storage locations in a storage media.

The present invention is based on the sensing of recorded

information or data on a storage media. The sensed or reproduced

data contains errors introduced into the first signal during

sensing of the information or data as a result of the transducer

or sensor being offset from the predetermined storage locations,

such as a track.

If the information or data as recorded or stored contains an

error, the sensed data likewise includes such errors in the data.

Such errors in the record data are different than any errors

introduced into the sensed data as the same is being sensed which

is the disclosure and teachings of this invention.

<div align="center">Description of the Figures</div>

Referring now to Figs 1 through 10, which describe several

embodiments of the present invention, the apparatus, methods,

detection systems and detection apparatus for reproducing data

using information about the extent of errors are described

hereinbelow.

In the pictorial representation of Fig. 1, apparatus for

using information about the extent of errors is shown generally

by arrow 20. A treated surface 22 of a storage media stores data

containing at least one constraint in the predetermined storage

locations 24. The data containing at least one constraint is

stored on the surface in the predetermined storage locations 24

during a write operation.

The data containing at least one constraint may take the

form of a number of data encoding techniques which have a known

<div align="center">-35-</div>

relationship with the data associated with the constraint. Use

of error coding techniques enable the true data to be determined

with greater likelihood than erroneous data, notwithstanding

errors, such as clutter or noise, which can interfere with

correct reading of data in an information storage system.

A transducer 26 is positioned for sensing the predetermined

storage locations 24 and generates a first signal representative

of the data containing at least one constraint stored in the

predetermined storage locations 24 and any errors introduced into

the sensed data during the sensing. The first signal is shown by

lead 30.

A input device, sometimes referred to herein as a detector,

34 is responsive to the first signal 30 for applying the sensed

data signal shown by lead 38 to a control signal generating

device, shown generally by box 42, for generating a control

signal containing information about the extent of errors. The

control signal is used for performing a control function as

described hereinbelow. The input device 34 extracts a data

signal shown as 56 as the reproduced data.

The control signal generating device 42 generates a control

signal containing information about the extent of errors which

may be used to perform the control function of controlling an

adjusting element 48. The adjusting element 48 is operatively

coupled to the transducer 26 by an actuatable assembly as

represented by dashed line 52. The adjusting element 48 through

the actuatable assembly shown by dashed line 52 adjusts or

repositions the transducer 26 in a direction to position the

transducer 26 in a direction to improve alignment relative to the
predetermined storage locations 24.

In a preferred embodiment, the adjustment element 48
includes an actuator, such as for example the actuator 104 in
Fig. 2B The actuator is responsive to the control signal applied
thereto by the control signal generating means to move or
physically realign the transducer 26. The transducer 26 is a
disc head in the preferred embodiment and is positioned to
improve alignment relative to the predetermined storage locations
24, or data track in the preferred embodiment. This movement or
realignment is in a direction to eliminate any mispositioning or
misalignment which the transducer 26 may have with regard to the
predetermined storage locations 24, or track. Thus, if the
transducer 26 is determined to be mispositioned or misaligned
from the predetermined storage locations 24, the transducer 26 is
physically moved right or left to position the transducer 26 in a
position to improve alignment relative to he predetermined
storage locations 24.

The transducer 26 of Fig. 1 may a first transducer which is
positioned relative to a second transducer as illustrated by box
62 in Fig. 2A. The first transducer and the second transducer
sense the predetermined storage locations and generate a first
signal and a second signal representative of data containing at
least one constraint from the predetermined storage locations and
any errors introduced into the sensed data during the sensing.
An input device generates the control signal from one of the
first signal and the second signal and extracts a first data
signal and a second data signal. An output device is responsive

to the control signal and at least one of the first data signal

and the second data signal to derive therefrom a data signal

containing the least amount of errors.

In addition the transducer 26 may be a first transducer

including at least two sensors for concurrently sensing the

predetermined storage locations and generating a first signal and

a second signal each representative of the data containing the at

least one constraint from the predetermined storage locations and

any errors introduced into the sensed data during the sensing.

In such event, the input device extracts a first data signal and

a second data signal as the reproduced data. In addition, the

input device 34 applies the first signal and second signal to the

control signal generating device 42 to generate a control

signal. In this embodiment, the control function is responsive

to the control signal and at least one of the first data signal

and the second data signal to perform at least one of generating

a dynamic servo signal and deriving from the first data signal

and the second data signal a data signal containing the least

amount of errors.

The block diagram of Fig. 2A illustrates one embodiment of

apparatus for using information about the extent of errors. The

data containing the at least one constraint is stored on storage

media, such as a recording medium 60 which interacts with a read

transducer 62 due to relative movement therebetween illustrated

by arrow 66. The recording medium 60 stores data containing the

at least one constraint in predetermined locations illustrated by

predetermined locations 24 in Fig. 1. The read transducer 62 is

positioned for sensing said predetermined storage locations on

the recording medium 60 and generates a first signal 70 that is

representative of the data containing said at least one

constraint and any errors introduced into the sensed data during

the sensing. The first signal 70 is applied to an input device,

or detector, 72 which is responsive to the first signal 70 for

generating a control signal containing information about the

extent of errors in the sensed data and for extracting data

signals. The control signal is applied to an output device 76.

The control signal is used to perform the following control

function in this embodiment.

The output device 76 reproduces the extracted data signal

from the sensed data as shown on lead 80. Concurrently, the

control signal and extracted data signal are applied to output

device 76 as shown by lead 74. In addition, the control signal

as shown by lead 82 is used to produce a dynamic servo signal

which are used to improve alignment of the transducer 62 relative

to the predetermined storage locations on the recording media 60.

In this embodiment, the dynamic servo signal are in the form of

substantially continuous servo signals, or position error signals

applied to a servo control, all of which are represented by

dashed line 82, to improve alignment of the transducer 26

relative to predetermined storage locations on the recording

media 60.

The block diagram of Fig. 2B is a more detailed block of the

apparatus of Fig 2A and illustrates the recording medium 60

interacting with a read/write transducer 90, a detector 92 and an

control device 100 which is an adjusting element, to control an

actuator 104 to adjust the position of transducer 90 via elements

represented by lead 108 in a similar manner as described in connection with Fig. 2A above. The detector 92 produces the reproduced data as shown by output 96. The control device 100 is responsive to the control signal from the detector 92 to generate position error signals, which is a dynamic servo signal appearing on lead 106 and the dynamic servo signal are applied to an actuator 104 via lead 106. The actuator 104 adjusts the position of the transducer 90 via elements represented by lead 108.

The apparatus illustrated in Fig 2B may also be used as a servo control during the write sequence or operation by virtue of the transducer having a read/write transducer. If the structure of the transducer enables a read and write at the same time, then a dynamic servo signal is continuously applied to the servo system to control head/track alignment.

If the structure of the transducer does not permit a read and write to occur at the same time, then the dynamic servo signal is disabled for the period approximately equal to a write period. Circuits for performing these functions are well known to persons skilled in the art.

The block diagram of Fig. 2C is yet another embodiment of apparatus for using information about the extent of errors. Fig. 2C illustrates the recording medium 60 interacting with a read transducer having two or more elements as shown by numeral 110. The transducer 110 generates a first signal 114 and a separate second signal 116, one from each element. The first signal 114 and the second signal 116 are applied to a input device 130 which generates a control signal as described hereinbefore and also extracts a first data signal and a second data signal. The

control signal is applied by lead 134 to a data signal selection

device 126 together with the extracted first data signal and

second data signal as represented by leads 130 and 132. In this

case, the derivation is a simple selection mechanism known as a

multiplexor. The data signal selection device 126 is responsive

to the control signal 134 and the first data signal 130

representing the first signal on lead 114 and a second data

signal 132 representing the second signal on lead 116 to derive

therefrom a data signal containing the least amount of errors.

Concurrently, the input device applies the control signal to

an adjusting element 144 via lead 142. In this embodiment, the

adjusting element generates a dynamic servo signal which are

applied to an actuator 150 via lead 146 to mechanically adjust

the position of the transducer 110 to improve alignment between

the transducer 110 relative to the predetermined storage

locations. In the alternative the adjusting element 144 can

generate an adjusting signal which can be used to electrically

shift one of or both of one of or of two or more sensors the

operating characteristics of one of the two or more sensors to

reduce the extent of errors introduced into the sensed data. An

example of such a transducer and structure thereof is discussed

hereinbelow in connection with Fig. 3E.

The apparatus illustrated in Fig. 2C enables an output

device to be responsive to the control signal to produce a

dynamic servo signal to improve alignment of the transducer

relative to the predetermined storage locations concurrently with

the derivation of a data signal containing the least amount of

errors from the first data signal and second data signal
developed from the two or more read sensors.

Fig. 3A, Fig. 3B and Fig. 3C are pictorial representations
of a treated surface 22 of a storage media depicting the width
160 assigned to a predetermined storage location or track on the
surface 22. The actual width of the predetermined storage track
storing data containing at least one constraint is shown by
dashed lines 164. The length of a transducer 26 is depicted by
length of side 170. The length 170 of the transducer 26 is less
that the width of the actual predetermined storage locations 164
and of the area assigned for the track 160.

Referring now to Fig. 3A, the transducer 26 is illustrated
as being positioned in substantial spatial alignment with the
predetermined storage locations or track 164 storing the stored
data containing the at least one constraint. In this position,
the transducer 26 reads the stored data with minimum errors.

In Fig. 3B, the transducer 26 is misaligned to one side, the
left side as shown in Fig. 3B, of predetermined storage locations
or data track 160. In this position, the transducer 26 is
misaligned and has a portion of the sensing element off track
relative to the predetermined storage locations or track 164 and
is off track and beyond the surface area assigned for the track
as shown by line 160.

In Fig. 3C, the transducer 26 is misaligned to the other
side the right side as shown in Fig. 3C, of predetermined storage
locations or track 164. In this position, the transducer 26 is
also misaligned and has a portion of the sensing element off
track relative to the predetermined storage locations or track

164 and is off track and beyond the surface area assigned for the track as shown by line 160.

Figs. 3D and 3E are pictorial representations of two embodiments of transducers having a write transducer and two magnetoresisitve sensors as the read transducers which may be used in the apparatus, system and method of the present invention.

In the pictorial representation of Fig. 3D, the transducer 26 has a write transducer 174 and two read transducers which, in this embodiment, are two magnetoresisitve elements 176 and 178 which have an insulative shield therebetween. The magnetoresistive elements 176 and 178 are at least two sensors supported in a fixed, spaced relationship to each other.

In the pictorial representation of Fig 3E, the transducer 26 is likewise a write transducer 174 and two read transducers which, in this embodiment, are two magnetoresisitve elements 176 and 178 which have an conductive shield therebetween which are responsive to an adjusting voltage to shift the magnetic operating characteristics of the magnetoresistive elements. By electrically shifting the magnetic operating characteristics of the transducer in addition to or in lieu of physically shifting or adjusting the position of the transducer with a servo system in response to position error signals, the extent of errors in at least one of said first signal and said second signal is reduced. In this transducer structure, the magnetoresistive sensors 176 and 178 are at least two sensors supported in a fixed, spaced relationship to each other.

When the transducer 26 of Figs. 3A and 3B is used in the
apparatus, system or method of the present invention, the
transducer includes at least two sensors for concurrently sensing
the predetermined storage locations and generating a first signal
and a second signal each representative of the data containing
the at least one constraint from said predetermined storage
locations and any errors introduced into the sensed data during
the sensing. In certain of the embodiments of the apparatus,
system and method, an output device is responsive to at least one
of the first signal and the second signal to produce a control
signal that is applied to and/or used to derive a data signal
containing the least amount of errors from the first data signal
and second data signal extracted from the signals from the two
sensors.

As discussed above in the Background, the future disc drive
systems are to have track widths that are smaller in width. The
read track widths are less than 50 microinches and smaller, and
the magnetic bit sizes on the stored surface 22 for magnetically
recording the data are also becoming smaller. As a result,
precise head/track alignment is very important in reducing errors
in the sensed data read from a predetermined storage locations or
track containing the stored data containing at least one
constraint and the apparatus described in Figs. 1,2A, 2B and 2C
above have utility for such applications.

In a preferred embodiment, the surface 22 is a magnetic
recording surface of a magnetic disc and the track 160 includes a
material responsive to electromagnetic fields so as to read or
write the data bits thereon, and such magnetic discs and

techniques for reading and writing magnetic data are well known in the art.

Although embodiments of the invention are described with regard to storage and retrieval of digital data using magnetic discs, the invention has wide applicability to other forms of data storage, such as for example optical discs, laser disc, digital video discs, holographic memories and the like. In general, the invention includes all those embodiments in which reading or writing data is responsive to a state of the art sensor with regard to an information storing medium.

In Fig. 4, the schematic diagram illustrates one embodiment of an apparatus for a rotating disc memory. The apparatus shown generally as 184 has a rotating recording surface 186 having a circular track shown by line 188 and having predetermined storage locations 190 storing data containing at least one constraint. A head 194 is mounted on the end of a head/loading arm 198 for loading and adjusting the head 194 relative to and in a direction to improve alignment with a track 188 relative to the predetermined storage locations 190.

In Fig. 4, the sensed data from the head 194 is applied via lead 200 to a transducer amplifier 202. The output from the transducer amplifier 202 is the first signal. The first signal is the sensed data containing the at least one constraint and any errors introduced into the sensed data during the sensing. The first signal is applied to a detector 204. The detector 204 generates a control signal containing information about the extent of errors which is used as a position error signal and applies the control signal to an adjusting element 206. The

adjusting element 206 than generates the position error signals
which are used to actuate the head/loading arm 198 as illustrated
by lead 208 to reposition the head 194 as required in response to
the position error signals. The detector 204 produces an output
signal represented by lead 210, which is the extracted data
signal used as the reproduced data.

In Fig. 4, the track 188 may include therein servo burst
signals illustrated by lines 192   The apparatus of Fig. 4 can be
used for using information about the extent of errors in
combination with servo burst signals generated from prerecorded
servo bursts. A new and novel method of using the prerecorded
servo burst in combination with the teachings of this invention
will be described hereinbelow.

The schematic diagram of Fig. 5 illustrates yet another
embodiment of an apparatus shown generally as 228 having a
rotating magnetic media recording surface 22 having a data track
164 having recorded data containing at least one constraint
stored thereon in predetermined storage locations or data track
164. A head/arm assembly shown generally as 230 includes an arm
232, a flexure 234 and a slider 236 having a transducer 26 having
two MR elements 176 and 178 forming a part of the slider 236,
which is known as a head/slider assembly. The head/loading arm
230 is used for loading and adjusting the transducer 26 relative
to the center line 240 of track 160 and predetermined storage
locations such as data track 164. The transducer 26 has two MR
elements or read sensors 176 and 178 and the MR elements 176 and
178 are staggered relative to each other and to the predetermined
storage locations or data track 164. An insulating layer or

shield 180 separates and shields the MR elements 176 and 178 to

reduce cross-talk and signal interference between the MR elements

176 and 178. Each of the MR elements 176 and 178 produce an

output signal appearing on leads 248 comprising the sensed data

containing at least one constraint and any errors introduced into

the sensed data during sensing. Each signal from each MR element

176 and 178 is applied to read amplifiers 250 and 252,

respectively. Also, for certain transducers where the sum of the

output signal is desired or required as part of generating a

control signal, each output from each of the MR elements 176 and

178 may be applied to a summing amplifier such as amplifier 254.

The transducer 26 in this embodiment is in the form of two

shielded MR elements. One example of such a transducer is an MR

element which is referred to as the Dual-Stripe MR Head offered

for sale by Headway Technologies, Inc., of Milpitas, California.

In the alternative, the transducer 26 may be formed of two

MR elements having a conductive shield as illustrated in Fig. 3E.

If such a transducer was used in the apparatus illustrated

in Fig. 5, the operating characteristics of the MR element could

be shifted electrically by use of a bias signal and such

electrical shift would be either in lieu of or performed

concurrently with the adjusting of the transducer by a servo

system in response to position error signals.

The MR element may be a single transducer 174. It is also

envisioned that in alternative embodiments, the transducer may

include three (or more) read sensors and/or two or more write

transducers. Such a structure would permit monitoring of and/or

deriving of sensed data containing the at least one constraint
from all elements.

The detector in this embodiment is capable of responding to
the control signal containing the at least one constraint and to
the extracted first data signal and second data signal developed
from the at least two transducers to derive a data signal having
the least number of errors. In this manner the reproduced data
is the extracted data signal having the least amount of errors.
In addition, the control signal containing information about the
extent of errors can be used to develop position error signals
for a servo system as described herein.

There is no requirement that the transducer 26, which in
this embodiment is a disc head, include any particular number of
read sensors, such as additional MR elements similar to MR
elements 176 and 178.

This invention is also effective using only a single MR
head, such as for example MR element 176, as discussed in
connection with Fig. 7.

The output signal of each MR element 176 and 178 provides
the sensed data containing the at least one constraint and any
errors introduced into the sensed data during sensing. These
signals are applied via their respective read amplifiers 250 and
252 and the outputs of the read amplifiers 250 and 252 are the
first signal and second signal. In the preferred embodiment, the
first signal and the second signal appear on output shown by
element 248 in the form of a time-varying electromagnetic signal,
e.g. a voltage signal, responsive to positions of the

corresponding MR elements 176 and 178 relative to the

predetermined storage locations or data track 164.

Each read amplifier 250 and 252 receives the first signal

and second signal representative of the sensed data containing at

least one constraint from its associated MR element 176 and 178.

The read amplifiers 250 and 252 each amplify the signal and

perform any other required signal processing. Such signal

processing may be for example conditioning the signal, converting

the signal to another format, e.g. a quantized digital format or

a remodulated format such as PCM.

The outputs 256 from the read amplifiers 250 and 252

(including the output from the summing amplifier 254 if required)

are applied to a detector 260 which in turn, generates a control

signal containing information about the extent of errors. In

this embodiment, the detector 260 applies the control signal

containing information about the extent of errors to an adjusting

circuit 270 which generates position error signals developed from

the control signal.

In the embodiment of Fig. 5, the detector 260 is responsive

to the first signal and second signal and, if required, the sum

signal, all of which are represented by leads 256. The detector

260 processes the first signal and second signal to determine the

at least one constraint in the data signal by computing the

errors or developing the errors by comparing the observed signal

with the expected signal. As an example, the detector 260 can

perform one or more of the following processing techniques for

extracting the data signal and generating a control signal

containing information about the extent of errors:

(1)   Add the components of the amplified first signal and amplified second signal to determine a unified first signal, from which the detector can extract the data signal and generate a control signal containing information about the extent of errors;

(2)   Subtract the components of the amplified first signal and amplified second signal to determine a differential therebetween which is used as the first signal from which the detector can extract the data and generate a control signal containing information about the extent of errors;

(3)   Use one or more of the components of the amplified first signal and amplified second signal to determine a unified or integrated first signal, such as for example, by weighing the first signal at one value and the second signal at a second value, e.g. 25% and 75%, respectively, and select, which is included in the meaning of derive, those components of each of the first signal and second signal for further processing to extract a data signal and to generate a control signal containing information about the extent of errors;

(4)   Process the components of the amplified first signal and amplified second signal separately to derive the extracted data signal containing the least amount of errors and generate a control signal containing information about the extent of errors; and

(5)   Process the components of the amplified first signal and amplified second signals to separately extract a first data signal and a second data signal and to generate a control signal which is used to derive a data signal having the least number of errors so as to produce separate signals, e.g. position error

signals, for horizontal displacement, angular orientation, or

vertical displacement of a transducer relative to the

predetermined storage locations, such as a track.

In this embodiment, the error detector 260 generates a

unified control signal which is applied to the adjustment element

230 to determine separate signals for horizontal displacement,

angular orientation and vertical displacement of the transducer

relative to the predetermined storage locations, such as a track.

In Fig. 5, the control signal appears on outputs 262 and is

applied to an adjustment circuit 270 which is responsive to the

control signal to produce two position error signals which are

applied to servo amplifiers 272 and 274. Servo amplifier 274

produces a component of the control signal containing information

about the extent of errors on lead 276 which is applied to a

coarse actuator 280 via lead 276 for moving or actuating the

head/arm assembly to position the same in a direction to improve

alignment with the predetermined storage locations, such as data

track 164.

The other position error signal from the servo amplifier 172

is applied via lead 284 to a fine micropositioner 286 which may

be an articulated end of an arm 232 for micromoving or

microactuating of the head/arm assembly to position the same to

improve head alignment with or to achieve substantial alignment

relative to the predetermined storage locations or data track

164.

The block diagram of Fig. 6 illustrates the method of the

present invention for using information about the extent of

errors. In Fig. 6, the method comprises step 300 positioning a

transducer in alignment with predetermined storage locations on a

storage medium. Step 302 provides for generating from the

transducer the sensed data containing at least one constraint.

Step 304 provides for generating from the transducer a first

signal representing the sensed data containing the at least one

constraint and any errors introduced into the sensed data during

sensing. Step 306 provides for generating in response to the

first signal a control signal containing information about the

extent of errors. Step 308 provides for performing in response

to the control signal and sensed data containing at least one

constraint a control function. The control function may be Step

310 providing for electrically deriving, such as for example

selecting, in response to the control signal containing

information about the extent of errors and from a plurality of

data signals, if a first signal and second signal is produced, if

more than one transducer is used or a transducer having at least

two sensors is used to sense the stored data, or combination of

sensed data signals that contain the least number of errors and

the reproduced data in the form of an extracted data signal from

Step 310 is shown by arrow 314. The reproduced data may be

directly used as the output as depicted by line 316.

Another control function is shown by Step 318 comprising

using the control signal containing information about the extent

of errors to generate a dynamic servo signal as illustrated by

lead 318 and applying the same to the adjustment element to

position the transducer using position error signal derived from

the control signal to improve alignment of the transducer

relative to the predetermined storage locations.

In the preferred embodiment of the present invention the method includes adjusting a magnetic transducer having at least two reading transducers or read elements with a servo system operatively coupled thereto for receiving as the dynamic servo signal derived from the control signal containing information about the extent of errors. The magnetic transducer is adjusted in a direction to position the magnetic transducer in improved alignment relative to the predetermined storage locations.

In the preferred embodiment, the at least two read transducers generate a first signal and a second signal and the Step 310 for deriving the sensed data signal having the least number of errors performs the deriving step using sensed data.

It is envisioned that variations of this method may be used for adjusting the position of a transducer having a plurality of transducers relative to predetermined storage locations containing data being sensed by the transducer.

In the method illustrated in Fig. 6, the stored data in the predetermined storage locations contains at least one constraint. It is also envisioned that the at least one constraint is PRML encoding.

In current state-of-the-art practice, a signal received from a transducer, such as for example in a rotating magnetic memory system, is processed using a technique known as Partial Response Maximum Likelihood ("PRML"). There are several known PRML encoding methods. The methods known as PR4 and EPR4 are commonly used. The example set forth hereinbelow is for use of the PR4 method. Use of other PRML encoding methods are similar.

In PR4 processing, the signal is sampled by an analog-to-digital converter ("ADC") at periodic intervals. The sampling is done synchronously with the signal. Since a PR4 encoding method is being used, only 3 values are expected which, for purposes of this example, are termed 1,0 and -1, if there were no noise decreasing the signal-to-noise ratio or other effects on the signal, such as non-linear transition shifts (hereinafter referred to collectively as the "Signal Deterioration Effects"), perturbing the signal. These values correspond to specific outputs of the ADC which correspond to voltages in the signals and these would be deemed the observed values of the signal. Due to the Signal Deterioration Effects, the observed values produced by sampling will differ from the 3 expected values described above. For example, instead of a voltage corresponding to a 1, as the expected value, a voltage that is .9 times this amount might be observed. The fact that only voltages corresponding to the 3 expected values 1,0 and -1, would occur only under ideal conditions represents one example of a constraint on the signal that is used to generate information about the extent to which a transducer is not aligned with a track center.

Over repeated observations, the contributions of the Signal Deterioration Effects to signal errors will contribute about the same amount of error independent of the degree of head/track misalignment. Other of these effects, such as head lift, only occur rarely and are mostly of short duration. Therefore, over repeated observations the errors due to head/track misalignment are observable.

In accordance with the teachings of the present invention, such a signal would be a control signal containing information about the extent of errors which could be used to perform a control function as described herein.

One feature associated with use of PRML encoding is that only certain sequences of values can occur within the encoded signal or the signal containing at least one constraint. For example, in the PR4 method, not all sequences of the expected 3 values of 1,0 and -1 will occur. The "maximum likelihood" part of the PRML encoding is used to choose a best estimate, based on the possible sequences of these values, of the theoretical values that the observed values can represent. The fact that only certain sequences of symbols will occur, and not others, is another at least one constraint that is used to estimate the extent of error.

As is well known in the art of PRML decoding, alternate sequences of possible decoded data sequences are saved until the sequence exhibiting the least extent of errors can be determined. This allows the choice of that sequence exhibiting the least extent of errors as that sequence with the maximum likelihood of having been the original recorded data sequence. The extent of error measure for the chosen sequence is then available to use in the invention as at least one component of the control signal of the invention.

In light of these constraints, the observed values are compared with known or expected values. As discussed above the observed values may differ from the expected values due to the Signal Deterioration Effects. For example, one such effect may

be due to the transducer rising temporarily to a greater height than normal off the disc surface due to encountering an aspersion, and then settling back to normal transducer flying height sometimes referred to as "head flying height". By computing or comparing the differences between the observed values and the expected values, the differences can be used to generate a control signal containing information about the extent of errors.

As the transducer or head passes over a track, each observation can be combined with a specific number of previous observations and the oldest observation can be dropped so that the degree of error or extent of error calculated represents that specific number of most recent observations. In this way, a dynamic signal or nearly continuous signal corresponding to the degree of misalignment can be generated and such signal represents a control signal containing information about the extent of errors.

In this method, the control signal is being derived from current data, that is defined to be data that is satisfying a read request to a disc drive or data in the same track preceding a write sequence to a disc or to a track on the disc.

The step 306 of generating a control signal also performs the step of extracting the PRML encoding from the first signal and compares the observed PRML encoding of the extracted PRML encoding with an expected PRML encoding and generates the control signal from the difference between the observed PRML encoding and the expected PRML encoding.

It is also envisioned that the teachings of this invention
have utility by using the method for using information about the
extent of errors in combination with servo burst signals
generated from prerecorded servo bursts. The method comprises
the steps of: (a) positioning a first transducer for sensing
prerecorded servo bursts and predetermined storage locations
having stored data containing at least one constraint and
generating in response to the prerecorded servo bursts servo
burst signals and in response to the stored data a first signal
representative of the data containing at least one constraint
from the predetermined storage locations and any errors
introduced into the sensed data during the sensing; (b) producing
in response to the servo burst signals a position error signal;
(c) generating in response to the first signal a control signal
containing information about the extent of errors in the sensed
data and extracting a data signal; and (d) receiving said
position error signals and said control signal and adjusting with
an adjusting element in the intervals between the servo burst
signals the transducer in response to the position error signals
to position the transducer in a designated alignment relative to
said predetermined storage locations and performing in the
intervals between the servo burst signals and in response to the
control signal containing information about the extent of errors
a control function to improve the extracted data signal as a
function of the extent of errors.

    The method can also include in the step of positioning
including a transducer having at least two read elements that
generate the servo burst signals and a first signal and a second

signal each representative of the sensed data and any errors

introduced into the sensed data during said sensing. The step of

receiving is responsive to the first signal and the second signal

to generate the control signal and for extracting a first data

signal and a second data signal. The control function between

servo burst signals performs with an output device at least one

of receiving the control signal for generating a dynamic servo

signal to improve alignment of the transducer relative to the

predetermined storage locations on said surface and being

responsive to the control signal and at least one of the first

data signal and the second data signal to derive therefrom a data

signal containing the least amount of errors. The method in the

step of positioning also includes the transducer being a

magnetoresistive element.

Fig. 7 shows a dashed line curve 330 which is a plot of the

bit error rate ("BER") as a function of the position of the

transducer relative to the center line of a track having stored

data containing at least one constraint in reading the stored

data from a predetermined storage location such as a sector of a

track. The BER is calculated after PRML processing. The curve

330 includes a first axis, the "X" axis, 332 showing the

horizontal position of the transducer, in the preferred

embodiment a disc head, relative to the width of the track, such

as data track 164 shown in Fig. 5. The curve 330 has as the

second axis, the "y" axis, the BER.

The response curve 330 shows that the BER curve is

substantially flat about -12 microinches to about +12 microinches

from the track center line of a track having a width of

approximately 50 microinches. The curve 330 includes two minimum

points 342 and 344 that correspond to the right and left

boundaries of the track, respectively. Between the minimum

points 342 and 344 and across the track width, head/track

misalignment does not produce a significant number of errors.

The portion of the curve 330 extending beyond minimum points

342 and 344 rapidly slopes up as the relative horizontal

displacement of the transducer increases from the center line of

the trace. At these points on curve 330, a slight change of

misalignment produces a significant change in the extent of

errors.

The solid line curve 338 is a plot of the average extent of

errors as a function of transducer position relative to the

center line of the track in a manner similar to the BER curve

330. The solid line curve 338 is an idealized extent of error

curve and beyond the minimum points 342 and 344 follows the BER

curve 330. However, at the range of 12 microinches to about +12

microinches from the center line depicted by numeral 340, curve

318 demonstrates that a slight change in alignment produces a

significant increase in the average extent of errors. This

information about the extent of errors is used as the control

signal and for generating a dynamic servo signal.

In the state of the art magnetic recording systems, the

servo burst produces servo signals at the a rate of about 8,000

to 10,000 servo signals per second. In the present invention,

the dynamic servo signal produced from a control signal

containing information about the extent of errors using the

teachings of the present invention result in a sampling rate

significantly higher than the sampling rate of the state-of-the-art servo systems.

As a result of the above, apparatus for producing the control signal containing information about the extent of errors can be used in combination with the known Servo Burst Method. In such a combination, the control signal is used to generate substantially continuous feedback signals containing information about the extent of errors and applying the same to an actuator for positioning the read/write heads to maintain head/track alignment such that the position error signals from the apparatus are used during the intermittent open loop servo operation between or in the intervals between the servo burst signals of the Servo Burst Method. In the Servo Burst Method, the sensing of a recorded servo burst is used to produce a servo signal for adjusting the head position relative to the data track.

As discussed hereinbefore, a single MR element any be used as the read transducer in practicing this invention. In the instance where a single MR element is used as the transducer, the sensed data containing at least one constraint and information about errors can be used to determine the magnitude of adjustment required by the adjusting element. However, the direction of the adjustment is difficult to derive from the sensed data containing at least one constraint and information about errors. In the prior art Servo Burst Method, the servo burst signal can be used to develop position error signals containing information about the magnitude and direction of adjustment.

In the present invention, the control signal can contain the information required to make such an adjustment of an MR element

by using the control signal containing information about the
extent of errors for the apparatus having a single MR element as
the reading transducer.

If the MR element is maintained slightly offset to one side
of the center line, this slight misalignment produces a high
average extent of errors. Referring to curve 338 of Fig. 7, an
offset of about 8 microinches produces a significant rate of
change in the average extent of errors as shown by line 346 on
curve 338. This significant change in the average extent of
errors can be used as an offset reference for the predetermined
head offset.

The apparatus disclosed herein using a transducer that is a
magnetoresistive sensor in a system where the predetermined
storage locations is a track having a center line and the
adjusting element is adjusted to position the sensor at a slight
offset from the center line of the track in a known direction
establishes a predetermined sensor position. In such an
apparatus, the output device is responsive to the control signal
containing information about the extent of errors to generate a
position error signal, compensated by the predetermined sensor
position, representing the magnitude and direction in which the
adjusting element is to move said sensor to improve sensor/track
alignment.

Thus, one servo control method for a single MR element or
single sensor is to maintain the head slightly to one side of the
track center between servo bursts. A small offset will provide
reproduced data having substantially the same number of errors
after PRML processing as compared to an ideal alignment of the

head with the track. This is due to the BER in the output of a

PRML processing not changing significantly as is evidenced from

curve 330 in Fig. 7. As the predetermined sensor position

approaches track center, the MR element or single sensor position

will be corrected so as to slightly increase its displacement

from track center. As the displacement is observed to increase

beyond a given amount, the head position is adjusted to decrease

the displacement. This method maintains the MR element alignment

or single sensor between an upper and lower limit.

If the MR element or single sensor is nearer the center line

of the track than a minimum displacement, then the direction of

the offset becomes unknown. In such event, an adjustment is made

to move the head slightly to the left. If the displacement is

observed to increase, then the MR element or single sensor was to

the left, otherwise the MR element was right. In this event, the

adjustment may have reduced the observed offset to zero. This

method can be repeated as soon as the offset is observed as shown

on the curve 338 of Fig. 7.

In Fig. 7, the BER curve 330 shows that as the MR element or

single sensor moves substantially off track, the signal-to-noise

ratio degrades to such an extent that the rate at which the

errors are observed after PRML processing increase substantially.

Each side of curve 330 represents a monotonically increasing

function of distance from track center. If the rate were

observable, i.e. if errors occurred frequently enough, when the

MR element or single sensor is close to track center, this

information could be used as a control signal in accordance with

the teachings of this invention. For current disc drives, in

which the BER is one in 10^7 or less most of the time, useful

observations occur too infrequently to be useful.

The idealized extent of errors curve 338 shows the shape of

the average extent of errors over a set of samples during PRML

processing. As described herein, a new value can be obtained

each time a new sample is obtained, which is in the range of

10,000 to 15,00 samples between each pair of servo bursts. This

is sufficient to generate a nearly continuous servo signal, and

is the preferred method in this invention.

Thus, slight changes to the MR element position which

increase or decrease track offset can be used to generate

information about the direction of track offset.

Fig. 8 is a plot of extent of errors as a function of head

location on a track for a transducer having two read transducers

or read sensors, such as for example the transducer illustrated

in Fig. 5. The plot of the curves is shown generally by numeral

400. The plot 400 includes a first axis, the "X" axis, 602 that

represents the horizontal position of a read transducer and a

second axis 404, the "Y" axis represents the extent of errors

observed during processing.

The first curve 410 shows the relationship between BER and

head position for a first read transducer and the second curve

412 shows the relationship between the BER and horizontal head

position for a second read transducer.

The response curves 410 and 412 are typical of the response

curves produced using the transducer 26 having two insulated MR

elements 176 and 178 in Fig. 5. This information can be used to

generate a position error signal for practicing this invention.

If a transducer 26 is used having two unshielded MR elements as depicted in Fig. 3E, the application of an adjusting signal on the conductive shield 182 shown in Fig. 3E will cause a shift in the magnetic characteristics of the magnetic operating characteristics of one of the MR elements. In Fig. 8, this shift is depicted by dashed curve 410'.

Figure 9 shows an example of a PRML response waveform and a extent of error waveform represented generally by numeral 500. The plot includes a first axis 502, the "X" axis representing "time", a second axis 504, the "Y" axis, representing "sensor voltage". The response waveform is shown by a solid curve 506 and is a plot of an actual response curve. The second waveform shown by dashed line curve 512 is derived from using a set of points, of which point 520 is an example, from a plot of a known or expected ideal waveform.

The actual waveform 506 shows changes in the time-varying electromagnetic value on the second axis 504 with time on the first axis 502 as actually measured by the transducer. The actual response waveform includes a plurality of sample points 520 indicating actual sample values of the time-varying electromagnetic value determined by the PRML technique.

The ideal waveform 512 shows changes in the time-varying electromagnetic value on the second axis 504 with time on the first axis 502 as the same would be measured by the sensor for an ideal case of bit-encoding and bit-decoding. The ideal response waveform 512 includes a plurality of sample points 520 indicating ideal sample values of the time-varying electromagnetic value determined by the PRML technique.

In general, the actual response waveform 506 differs from the ideal response curve 512. The transducer receives the actual values for the actual sample points 520 and a comparator compares those values with the ideal sample values, and determines a set of sequences of data bits most likely to have produced the actual values for the actual sample points 520.

It is envisioned for one embodiment that the PRML encoding technique can be selected as a constraint for the data signal for practicing this invention in the following manner. The signal from the sensors, e.g., MR elements, can be sampled at twice the normal sampling rate or higher. After PRML decoding, using sample points as discussed hereinabove, the difference between the observed PRML encoding waveform from the sensor, e.g., MR head, and the expected PRML encoding as derived from the error corrected output data is computed. This computation provides information about the extent of errors in the sensed data signal and can be used for the control signal. Such computation is available using the computational capacity of state-of-the-art microprocessors and digital signal processors.

The following are examples of determining error rates using PRML processing: (a) The average amount by which the observed values of samples differs from the expected values of these samples, when averaged over a span of samples, which span of samples may range from a few tens of samples to a thousand or more samples; (b) the average amount of the squares of the above difference over the same range of sample sizes; (c) the average amount of squared differences between a PRML signal re-encoded from the error-corrected data output of the invention and the

sensed signals, properly aligned in time, applied to each of the

first data signal and second data signal that is input to the

PRML decoders, to provide a measure of extent of error

measurement that corresponds to the data stream produced by each

PRML decoder and from which the control signal is composed; The

advantage of this is that the best estimate of the expected PRML

signal is that output signal that has been derived from the first

data signal and the second data signal and has subsequently been

PRML decoded, and possibly further error corrected as the best

data output signal from the invention; and (d) other functions of

these differences for these sample sizes.

When two MR elements are employed, a control signal is

calculated for each in the above described manner. Then a

function of all of these individual control signals combines then

to produce and output control signal. there are many ways to

combine the signals. The simplest is to subtract the first

control signal from the second control signal and use the result

as the control signal.

Figure 10 shows a process flow diagram of a method for using

information about the extend of errors.

The method applies to the step of positioning using a

transducer or transducers including transducers having two or

more read elements to sense predetermined storage locations

having stored data containing at least one constraint. The

method utilizes the apparatus described herein above and is based

on predetermined storage locations containing data being already

written on or within a storage media.

At flow point 600, the sensor is positioned proximate to the predetermined storage locations or data track and is ready to read a sequence of data bits. At flow point 602, the transducer responds to the sequence of data bits and produces a first signal. At flow point 604, the detector or input device processes the first signal by comparing the first signal having at least one constraint with the expected signal containing the at least one constraint to generate the control signal containing information about the extent of errors. The flow point 606 also extracts the data signal from the first signal.

At flow point 606, the extracted data signal and the control signal containing information about the extent of errors may be used as shown by flow point 610 for electrically deriving a data signal having the least number of errors from multiple data signals and to produce the so derived data signal as the reproduced data 614. The extracted data can be used as the reproduced data as shown by lead 612.

At flow point 620, an adjusting element responds to the control signal containing information about the extent of errors to generate position error signals that are used to adjusting the position of the head such that the head is positioned in improved alignment relative to the predetermined storage locations or data track thereby continuing the read process as shown by flow point 640 extending back to flow point 600.

In the schematic diagram of Fig. 11, this embodiment of the apparatus is a variation of the apparatus illustrated in Fig. 5. In Fig. 11, apparatus shown generally as 650 has a rotating magnetic media recording surface 22 having a data track 160

having recorded data 164 containing at least one constraint

stored thereon in predetermined storage locations or data tracks

160.   A head/arm assembly shown generally as 652 includes an arm,

a flexure and a slider similar to that illustrated in Fig. 5, for

supporting and adjusting a transducer 26 having two MR elements

176 and 178, having therebetween the insulating layer or shield

180, which are staggered relative to each other and to the

predetermined storage locations or data track 164 in a similar

manner as the transducer illustrated in Fig. 5.

Each of the MR elements 176 and 178 produce an output signal

appearing on leads 248 comprising the sensed data containing the

at least one constraint and any errors introduced into the sensed

data during sensing.   The signal from MR element 176 is applied

as an input to read amplifiers 250 and 254 while the signal for

MR element 178 is applied to read amplifiers 252 and 254.   The

output of read amplifier 254 represents the sum of the signals

produced by MR elements 176 and 178.   The output of read

amplifiers 250 and 252 represents the signal produced by MR

elements 176 and 178, respectively.

The output signals of read amplifiers 250,252 and 254 each

separately provide the sensed data containing the at least one

constraint and any errors introduced into the sensed data during

sensing.   Each of the read amplifiers 250, 252 and 254 amplifies

the signal and performs any other required signal processing and

generates a first signal representative of data containing the at

least one constraint from said predetermined storage locations

and any errors introduced into the sensed data during sensing.

Each of the read amplifiers 250, 252 and 254 applies its respective output as the first signal to parallel detectors.

Specifically, the first signal from read amplifier 254, which is a sum of two signals sensed by the MR elements, is applied as an input to a sum data extraction and error circuit 700 that produces an extracted data signal on output 710 representing the sum of the two signals sensed by the MR elements 176 and 178, and a control signal having information about the extent of errors which appears on output 720.

Similarly, the first signal from read amplifiers 250 and 252, which are the signals sensed by the MR elements 176 and 178, respectively, are applied as an input to a left data extraction and error circuit 702 for the sensed signal from MR element 176 and to a right data extraction and error circuit 704 for the sensed signal from MR element 178, respectively. The left data extraction and error circuit 702 produces an extracted data signal on output 712 extracted from the first signal from MR element 176 and a control signal having information about the extent of errors which appears on output 722.

The right data extraction and error circuit 704 produces an extracted data signal on output 714 extracted from the first signal from MR element 178 and a control signal having information about the extent of errors which appears on output 724.

In this embodiment, the sum data extraction and error circuit 700 generates a unified control signal while the left data extraction and error circuit 702 and the right data extraction and error circuit 704 each generate a control signal

containing information about the extent of errors in each
received signal.

In the embodiment of Fig. 11, the following two control
functions are performed with respect to the extracted data
signals 710, 712 and 714 and control signals 720, 722 and 724.
The extracted data signals 710, 712 and 714 are applied as an
input to a data multiplexor 732 which, in response to a
processing control signal received via lead 736 from a selection
controller 734, performs a derivative operation which is
responsive to the processing control signal 736 and at least one
of the extracted sum data signal 710, the extracted left data
signal 712 and the right extracted data signal 714 to derive
therefrom a data signal containing the least amount of errors.

The control signals 720, 722 and 724 are concurrently
applied to the selection controller 723 and to a servo controller
724.   The selection controller is responsive to the control
signals to generate the processing control signal 736 applied to
the data multiplexor 732 as described herein before.

The servo controller 723 generates position error signals
from the control signals and applies the same via lead 726 to a
servo amplifier 728.   The servo amplifier 728 applies the servo
signals representing the magnitude and direction of the
adjustment required to improve alignment between the MR elements
and data track 160.

The embodiment illustrated in Fig. 11 can perform either one
or both of the derivation of data functions via the multiplexor
732 and using the control signals to generate a dynamic servo
signal in the form of substantially continuous servo signals.

Fig. 12 is the voltage of the sensed signal from each MR element 176 and 178 and the sum of voltages from both MR elements 176 and 178 plotted as a function of off track locations. The response curve 742 is representative of MR element 176 and response curve 744 is representative of MR element 178. Response curve 746 represents the sum of the sensed signals from MR elements 176 and 178. These signals represent the first signal applied to the applicable input device or data extraction and error circuits illustrated in Fig. 11.

The multidisc storage system illustrated in the diagrammatic representation of the Fig. 13 is another embodiment of the present invention for generating a dynamic servo signal which is in the form of a substantially continuous servo signal which can be used to develop position error signals at a higher rate than the state-of-the-art storage system using the Servo Burst Method.

As illustrated in Fig. 13, disc drives 750 are currently being built which have plurality storage discs, discs 1 through N, as represented by discs 752 and 754. The discs are operatively connected to and adapted to be rotated by a spindle 760. A plurality of transducers 764, 766, 768 and 770 are supported by a support 800 and loading arms represented by dashed line 774 in operative relationship relative to the applicable disc surfaces of disc 752 and 754.

In Fig. 11, the disc surfaces may be an upper and lower surface on the same disc, e.g., disc 752, or disc surfaces on different discs, e.g., upper surface on disc 752 and upper surface on disc 754.

When the disc surfaces are on the same disc, physical
conditions which introduce errors into the sensed signal, e.g.,
thermal expansion, bending or the like, affect both surfaces more
or less equally thereby reducing errors between the transducers
sensing data from surfaces on the same the rotating disc. When
the disc surfaces are on different discs driven by a common
spindle, physical conditions which introduce errors into the
sensed signals, e.g., spindle wobble, affect both discs more or
less equally thereby eliminating some errors between the
transducers sensing data from surfaces on different rotating
disc.

The transducers 764, 766, 768 and 770 sense the stored data
and apply the sensed signals to their respective read amplifiers
782, 784, 786 and 788, respectively.

The outputs from each of the read amplifiers 782, 784, 786
and 788 are applied parallel to an input device 974 which derives
a single extracted data signal therefrom which appears as output
798. The input device 794 generates a control signal containing
information about the extent of errors from the plurality of
first signals, and generates a dynamic servo signal which appear
on lead 806. The control signal on lead 806 is applied to
actuator 804 to adjust the position of one or more of the
transducers 764, 766, 768 and 770 to improve transducer alignment
relative to a track on the disc surface. The control signal
shown in arrow 808 may be used in a manner similar to Fig. 12,
being applied to a data multiplexor through a selection
controller.

As illustrated in Fig. 13, the transducers that address or which are placed into operative relationship with all of the disc surfaces move together as a part of a single transducer stack assembly generally known in the art as head stack assembly. When one of the transducers on a first disc surface is well aligned with a track and is reading or sensing data from that track, the transducers on the other disc surfaces are approximately aligned with the tracks on those other disc surfaces.

As a result of the high manufacturing tolerances necessary to achieve current track densities, and of operating environmental conditions introducing thermal and other effects that cause the transducer to transducer alignment to vary over time, information about the position of a transducer on a second disc surface is not sufficient to accurately control the position of the transducer on the first surface so as to be able to align that transducer with the required accuracy over a track on the first disc surface.

The apparatus of Fig. 13 can be used to provide information about the extent of errors by processing signals sensed from one or more of the other disc surfaces in the same manner as has already been described for a first signal from a transducer sensing or reading data from the first surface. This information is used to detect relative movement between the head of the disc storing the data and to transmit this to the input device. The input device 794 uses this information in combination with the information received from the control signal containing information about the extent of errors in the first signal to

improve the alignment of the first transducer relative to its data track.

Such additional information may be obtained from one or more of the other disc surfaces storing data in the disc drive. When the disc surfaces are on the same disc, the sensed data from the first transducer's reading is particularly useful, e.g., can be used to generate a single control signal to adjust both transducers to improve alignment of both transducers relative to its associated track. During manufacturing of a disc drive, a manufacturing step called "servowriting" is used in which servo burst are written for every track and every surface. It is envisioned as part of this invention to align tracks on opposite surfaces of the same discs, so that the track centers on the first surface are somewhat offset from the track centers on the second surface during servowriting. Thus, when a transducer on one surface is well aligned with a track on the first surface, the transducer on the opposite surface is somewhat misaligned with a track on the opposite surface. When this occurs, the relationship between the transducer and track on the opposite surface is such that the extent of errors is large.

As shown in Figs. 7 and 8, the rate that the extent of errors (BER measured during PRML processing) changes by large amounts as the alignment of the transducer with the data track changes. Therefore, the second transducer will be operating in alignment with the second track such that the extent of errors is a very sensitive measure of the change in alignment between the transducer and track, increasing its usefulness as a second control signal applied to the control device 794.

It is also envisioned to write the servo burst on opposite
surfaces of a disc so that the servo burst on one surface are
positioned half-way between pairs of servo bursts on the other
surface which can be easily accomplished during servowriting. As
a result, information from the servo burst on the second surface
can be provided to the control device 794 during the intervals
between generation of information from servo burst on the first
surface. These control signals may be used in the intervals
between the servo burst signals to adjust transducer position
relative to a track on a nearly continuous basis.

<div align="center">Summary</div>

It is envisioned that the teachings of the apparatus, method
and system as disclosed has application in storage systems in
which the storage medium is moved in relation to the transducer,
including magnetic disc drives, both hard and floppy disc
application, in magnetic tape drives, magnetic card stripes or
the like. Any storage apparatus which utilizes magnetic
responses, including magnetic induction, magneto-resistive
sensors, including "giant magnetoresistive" transducer, "colossal
magnetoresistive" transducer and spin-valve transducer are deemed
to be within the teaching of the present invention.

In addition, it is envisioned that the teachings hereof
would have utility for storage systems employing electric and
other forces as sensed by an appropriate probe such as is used in
atomic force microscopes and other microscanning devices.

In addition, it is envisioned that the teaching hereof would
have utility for optical data storage or other storage systems

including holographic memories which record and reproduce stored

data in predetermined storage locations.

All of the above are envisioned to be useful for practicing

the invention as disclosed herein.

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